2.—THE GEOLOGY AND PHYSIOGRAPHY OF THE LOWER CHITTERING AREA.

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I.—INTRODUCTION

When travelling northwards along the main Perth-Gingin road at about twelve miles from Perth one sees, rearing up steeply a few miles to the east, the sharp straight line of the Darling Fault Scarp which forms the western margin of the Darling Peneplain (Jutson, 1913). As one approaches Bullsbrook, some 30 miles north-east of Perth, one may notice, however, that the topography of the country is changing, nearly all trace of the typical clean-cut, steeply sloping scarp face becoming lost in broken spurs and numerous deeply dissected, flat-topped hills.

In this country at about 37 miles by road north-north-east of Perth is situated the Lower Chittering Area which covers about twelve and a half square miles, its southern boundary being about half a mile north of the junction of the Chittering Brook with the Swan, or (as it is here called) the Avon River.

The area under discussion is very sparsely populated, in the south there being one or two farms devoted to mixed farming. Here some slopes are being cultivated for wheatgrowing and for sheep pastures. In the northern part of the area there are several small orchards growing citrus fruits. Farther north of the area, the valley of the Chittering is more thickly settled and carries numerous orchards famous for their oranges.

To the south and nearer Perth the country, some areas of which have been mapped in detail (Clarke & Williams, 1936; Fletcher & Hobson, 1931), consists of granitic rock invaded by a younger granite and by still later basic dykes, whereas this area contains portions of a complex system of metamorphosed rocks probably of Yilgarn age, for which I propose the name Chittering Series. This series is probably older than, or at least a lower portion of, the metamorphic rocks of the Jimperding Area—known as the Jimperding Series, which have recently been mapped (Prider, 1932-4).

As is pointed out later, the Chittering and Jimperding Series both form part of a belt of complex metamorphic rocks which extend northwards past Moora, and south-eastwards from Jimperding to Clackline and York. Apart from the detailed work of Prider (cited above) on these metamorphics, Dr. E. S. Simpson has written a number of papers (1926, 1928, 1930, 1932, 1936) dealing with the occurrence of some of the interesting rocks and minerals to be found in this metamorphic belt, while Mr. J. E. Wells has been responsible for the discovery in the field of many of these minerals.

Detailed geological mapping of the area was commenced in 1935 when portion of the southern half of the area was mapped by a party of Senior Geology students including the author, the rest of the field mapping and most of the levelling being completed by the author, working alone, during the following year (1936).

The area has been subdivided by the Lands and Survey Department, thus obviating the need for preliminary survey work. Detailed mapping of geological and topographical features was done in 1935 by chain and compass traverses, but when working alone the author relied entirely on pace traverses and frequent triangulation of bearings. Levelling sufficiently accurate for the drawing in of form lines was done by aneroid barometer, using the Trig. Station W.T. in the south-eastern corner of the area as the datum.

II.—PHYSIOGRAPHY.

A.—*General Relief.*

Topographically, this area varies from one of fairly young to early mature age of stream dissection, the rather close grouping of the form lines, as seen in the accompanying map, testifying to the high relief and rather rugged character of the country, particularly on the eastern side of the area. The streams are cutting down into portion of a table land, the Darling Plateau or Peneplain, the old level being clearly seen as laterite capped hills of a very constant height which never exceeds 900 feet. These laterite capped hills are a notable feature of the area; a large "island" of laterite with cliff-like edges showing deep embayments due to the headward erosion of the creeks, stands out in marked relief, a little to the west of the centre of the area, while most of the south-eastern, eastern, and north-eastern, and portions of the extreme south-western boundaries of the area consist of laterite-topped highland.

According to Jutson (1913), the Darling Peneplain was uplifted in pre-Pleistocene, probably late Pliocene time, its western edge forming the Darling Fault Scarp. As a result of this uplift many streams were either dislocated or rejuvenated, and the present topography reflects this renewed cycle of erosion.

The principal drainage channels of the area have been formed by systems of small tributaries which feed either the Chittering Brook or one of its three major tributaries—Marda Brook, North Brook and Banksia Gully. The valley of the Chittering in this area is distinctly younger than the valley of the Upper Chittering which lies north of the area under discussion and which shows the lower relief and sweeping profiles of maturity.

B.—*The Chittering Brook and its Tributaries.*

1. *The Chittering Brook.*

The Chittering Brook enters the area at approximately the centre of its northern boundary and thence flows for about 1½ miles in a general south-easterly direction, by a series of irregular zig-zags alternately transverse and parallel to the strike of the country rocks. It then turns sharply S.W. following the changed strike of the country for half a mile when it swings southward. About half a mile farther on the Brook turns abruptly S.S.W. following the contact of a gneissic granite with felspathic quartzite for some twenty chains and then swings sharply S.S.E. into the granite and flows in a general southerly direction out of the area for one and a half miles to its junction with the Avon River.

The zig-zag nature of the northern portion of the Brook and its marked adjustment to the structure of the country throughout suggests that it may be either (a) a "superposed subsequent" stream (Cotton, C. A., p. 133); that is, an original stream which flowed in a general south-easterly direction on the duricrust or possibly upon other unconformable rocks of the Darling Peneplain, and which, following the Darling uplift, has cut down into the underlying metamorphics and accommodated itself to their structure, or—

(b) A consequent stream developed from an older drainage system of which the Upper Chittering may originally have formed a part, by uplift of the peneplain, the original south-easterly direction of flow being modified in recent times by adjustment to the structure of the rocks which it is traversing.

The Chittering Brook is a perennial stream and though very sluggish during the summer months, it flows rapidly during the wet season and is heavily laden with silt.

Along both banks there are traces of a terrace which varies from 0-5 chains wide at 10-15 feet above the present water level and suggests a recent rejuvenation of the stream, but as the brook very seldom overtops its banks no extensive deposits of alluvium are to be found in the area.

2. *The Tributaries.*

The tributaries of the Chittering Brook are for the most part small streams which flow only after heavy rains. There are, however, three nearly perennial though still intermittent tributaries:—(a) Marda Brook, (b) North Brook on the left bank, and (c) Banksia Gully on the right.

(a) *Marda Brook and its Tributaries.*—This brook flows in a general west to east direction across the southern part of the area crossing the strike of the country until some 15 chains from its junction with the Chittering where it swings north-eastwards along the contact of gneissic granite and the metamorphics and then turns E. to join the Chittering just below the point at which that stream enters the granite.

Marda Brook is rather immature, with an unsymmetrical valley having steeper slopes on the north side in general than on the south side. Its tributaries are of two types—those which enter on the north side being short, straight, parallel, insequent streams of steep grade, cutting headward into the laterite "island," and those which enter on the southern side being, in general, longer and less regular, with lower grades. Of these No. 2 Creek can be seen cutting across the strike of the rocks except in its upper reaches where it swings south-east parallel to a broadly swerving outcrop of ferruginous mica schist. This south-western portion has much lower relief than the rest of the area.

(b) *North Brook* flows in a broad V-shaped valley near the northern boundary of the area. It swings from a curved north-easterly to easterly direction and joins the Chittering Brook at a point where it turns northward about 20 chains east of the turn-off of Plunkett's Road from the Lower Chittering Road. In its lower reaches, North Brook is fairly mature and flows through a terraced bed of alluvium.

This brook possesses a number of tributaries on both the northern and southern slopes of its valley, all of which are typically strike streams. The two most western of its tributaries, Contact Creek and Prospect Creek, are long, parallel, straight watercourses, running along geological boundaries and having rather steep V-shaped valleys. The divide between these two streams is a long straight ridge of porphyritic gneiss of a fairly constant height of approximately 700 feet.

Numerous small insequent tributaries on the eastward slope of Prospect Creek show marked headward erosion into the central laterite plateau.

(c) The creek which flows through *Banksia Gully* enters the area at its north-eastern boundary, flows due west across the granite gneiss and then describes an irregular arc facing southwards, and passing through a steep narrow gorge, travels on westward across the strike of the country rocks to join the Chittering. The tributaries of this stream are for the most part short and straight with a steep grade.

The other tributaries of the Chittering may be divided into two types:—

(1) Those on the eastern and central western slopes are roughly parellel insequent streams cutting into the laterite plateau whose boundaries form shallow cliff-like structures reminiscent of breakaways. (Talbot and Clarke, 1917, p. 43.)

Near their sources several of the streams on the eastern slopes are mature while in their middle parts the grade is steep, flattening out again in their lower levels. This is probably due to the fact that in their upper reaches, the creeks are traversing solid resistant granite, but farther westward they cross the contact of granite with the softer metamorphics. Here, owing also to the broken and jointed character of the rocks, erosion has proceeded rapidly and the streams have cut deep gorges, through which they plunge, to be checked at the foot of the slopes where they enter the Chittering.

(2) The tributaries of the north-western slopes, *e.g.*, Wilson's Creek and Camp Creek, are moderately mature streams which in part show some adjustment towards the strike and dip of their bed-rocks.

3. *Springs.*—Springs are of frequent occurrence in the metamorphic rocks of the area except in the gneissic granite country where they are seldom seen. They never occur on the laterite plateau which is well above the water table. During the summer months they are the most reliable sources of fresh water. They are most frequently found emerging from the cleavage planes of acid gneisses, or from the contacts of a basic dyke with gneiss. Occasionally on the slopes of the north central area several springs may be seen issuing at irregular intervals along a line of constant height. These springs have a remarkably constant flow. A large spring on the property of Mr. F. Wilson, about 15 chains S. of the Plunkett's Road Bridge, has been claimed to yield 6,500 to 7,000 gallons a day.

In the upper reaches of Wilson's Creek a spring of saline character issues from the boundary of a dolerite dyke although the water from a second spring in gneiss some 5 chains down stream is quite fresh. The water of the Chittering Brook is markedly saline in summer from the frequent presence of salts in solution in many of its tributaries, especially those which cross sheared and unsheared basic dykes. No analyses of these waters have, to the author's knowledge, been made.

4. *Sub-surface Drainage* (Aurousseau 1919).—A special feature of this area is the occurrence of underground drainage channels which open into the banks of the creeks. Their presence is revealed by an occasional "sink hole" and in one short easterly flowing tributary in the centre of the area a channel with a sectional area of over 4 square feet was noticed. These channels eventually collapse and are quickly scoured to form a new insequent tributary. In some of the cultivated areas so rapid is the denudation of the surface soils that farmers are faced with the grave problem of checking this waste. In two places in the southern half of the area small landslides of soil covering very steep dolerite talus slopes have occurred due to undermining of this subsurface drainage.

III.—GEOLOGY AND PETROLOGY.

A.—Structural Geology and Field Distribution of the Rocks.

1. *The Rocks.*—The rocks consist of a very complex series of metamorphics with later acid and basic igneous intrusives.

The metamorphics—the Chittering Series—are an apparently conformable series of gneisses, schists, and felspathic quartzites which frequently show but ill-defined boundaries one with another. All of these rocks show signs of fine crumpling or "drag folding" in different places. They strike typically north and south with local variations up to 45° to the east in the north-eastern corner of the area and there are traces of an arcuate fold in the outcrops of the central southern portion of the area. The dips are uniformly steep, being characteristically vertical, but vary from seldom less than 70° either to the east or to the west. The thickness of the different types is very variable and the bands are often rather impersistent along the strike, either disappearing under mantles of cultivated soil, or talus of the central laterite plateau, or lensing out at some points, whence often very little trace of them can be found. This is especially the case with the micaceous schists.

Cutting across the south-western part of the area, the contact line running in a constant north-east—south-west direction, is a medium-grained, typically-massive acid rock which appears to be a slightly crushed gneissic granite. Although the actual contact of this rock with the Chittering Series is obscured for the most part by rubble and talus slope, the boundary has been mapped as accurately as possible to within a chain or so. In general the boundary of this granitic rock appears to be roughly parallel to the strike of the adjacent metamorphics. This boundary line does not reflect the principal structural features of the Chittering Series and can be explained either as an unconformity or as the contact of an intrusive rock into the older metamorphics. However, in the extreme east of the area the granitic rock appears to be definitely intrusive into a micaceous schist and the general character of the rock in the field is that of an acid intrusive, while a microscopical study leaves little doubt of its igneous origin.

The rock extends to the east under the laterite outside the area studied for an unknown distance, and also appears to stretch some distance southwards, and may possibly be connected with the granitic rocks of the Upper Swan area. In the south, at its contact with the metamorphics, the granite shows some vertical jointing parallel to the boundary line, which gives it a vertically bedded appearance, but farther east it is quite massive, the outcrops occurring typically as low, gently rounded mounds or sloping floors.

The metamorphic rocks and the granite have both been invaded by acid and basic dykes. The acid dykes which are rare compared with the basic types, are biotite and muscovite pegmatites, graphic pegmatites, aplite and quartz veins. They are very irregular in size and distribution, and are usually traceable for short distances only. It is possible that there are two ages of pegmatites represented in the area, as in some of the acid gneisses are found irregular lenses and folded bands of a coarse pegmatite which appears to have suffered dynamic metamorphism along with the intruded rock, while in other places the pegmatites cut across the strike of the gneiss, and show little if any deformation.

The author is inclined to believe that there were two periods of acid intrusion, the first of which was the time of the "granitisation" of some of the schists, the apparent grading of the pegmatite into gneiss being a consequence of this process and the irregular folding seen in places being of "ptygmatic" type (Sederholm, J. J., 1923, p. 85, 1927, p. 25 *et seq.*), due to fluidal movements of the plastic injected rock. The younger pegmatite was probably the last phase of the intrusion of the gneissic granite.

The basic dykes have a general trend N.N.E., but in the south-western section of the area they swing round from N.E. to east. They are very numerous in the central and eastern parts of the area, but are less frequent on the western side of the central laterite plateau, while in the extreme western side of the area, in mica schist country, no dolerites at all were found.

The basic intrusives are of two types which are genetically related.

1. Dolerites and associated epidiorites.
2. Hornblende schists.

1. The dolerites and epidiorites form the principal type of dyke. They are very abundant and appear to radiate fanwise to the north and to the south-west from the centre of the area.

These dykes, some of which, to be exact, are vertical "sills," since they frequently follow the bedding-planes of the metamorphics, vary in width from less than half a chain to three or four chains; some are traceable for more than a mile, while others can only be followed for a few chains; some branch and occasionally anastomose at junctions appearing to be quite continuous, with no sign of one branch cutting through the other, whence it appears that the dykes all belong to one period of intrusion. They are true "fissure dykes" (Sederholm, J. J., 1926, pp. 34-5), and have formed from the invasion of basic magma from below along cracks in granite and in the metamorphics. The dykes are usually finer grained along their edges than in the centre and the narrower dykes invariably have a much finer grain than the wide ones.

2. The hornblende schists occur in narrow dykes never more than a chain in width and rarely exceeding 30 chains in length. The field relations and microscopical examination of these rocks show that they were originally epidiorites which have been subjected to stresses producing an orientation of the predominant amphibole parallel to edges of the dyke, with the resultant schistose structure.

Many of the hornblende schists strike parallel to larger dolerite dykes, and in several places dykes have been found which show on either both or only one of their edges a definite schistose structure while their centres are massive, similar to medium fine-grained altered epidiorite. Also in places narrow dykes of hornblende schist appear to grade along their strike into massive fine-grained epidiorite.

The above statement, together with the fact that nowhere have the dolerites or epidiorite been found intersecting the hornblende schists seems to suggest that the basic dykes all belong to the same period of intrusion. Possibly during the intrusion the country was subjected to stresses which produced the schistose structure in some of the dykes. No parallel structures would be produced in the larger intrusions which were still in a fluid state, but many of the narrow dykes which were more rapidly chilled, and had already solidified, would have been unable to yield to the stresses as a liquid, but only by deformation of the still cooling magma, resulting in a parallel orientation of the amphibole perpendicular to the directions of stress.

Those dykes which show schistose structures along their margins but are more massive in their central parts may have yielded to the stress by recrystallisation at their edges and so protected their centres.

The relationship of the dolerite to the pegmatite intrusions is clearly seen in the south between No. 1 Creek and No. 2 Creek where two small dolerite dykes cut across an outcrop of graphic pegmatite, which is thus the older rock.

Later superficial deposits in this area are duricrust and alluvium. The duricrust is well developed in the central plateau and in the extreme south-west corner of the area. It is of two types:—

1. Pisolitic laterite typical of the Darling Range districts. (Simpson, E. S., p. 399, 1912, and Clarke, E. de C., 1919.)
2. Ferruginous grit.

The laterite is a high level form which occurs at a constant height of about 800 feet and is from 50 to 75 feet thick at its thickest parts. It appears to have developed equally well over all rocks. The ferruginous grit is seen in the form of loose boulders and broken fragments of dark red limonite in which are embedded grains of quartz and muscovite. This grit occurs on the slopes below the pisolitic laterite and may possibly be compared with the ferruginous sandstone found in the Upper Swan area (Fletcher and Hobson, 1931-2).

Alluvium is present in a narrow strip along the flood plain of the Chittering Brook.

2. *Structure.*—The complicated and often highly folded nature of certain of the rock types, the frequent difficulty of following geological boundaries, and the rapid variation in mineralogical composition of the metamorphics, both across and along the strike, make one very cautious in attempting to elucidate the structure of the area.

Probably a great deal more field work and mapping, particularly of areas to the west and east of the present locality will be required before the key to the true interpretation of the major structures will be obtained.

A study of the minor drag folds in certain parts of the area has suggested explanations of portions of the structure but no doubt more detailed examination of the dragfolding in adjoining areas would furnish many valuable clues as to the ultimate structure of the metamorphics in this district.

Unfortunately much of the dragfolding in this area is so involved that a reliable interpretation of it appears well nigh impossible. The folding throughout the area has been intense, the angles of dip of the various rocks rarely being less than 70° and most commonly being over 85°. The strike varies from a little east to slightly west of north.

Readings of good dragfolding, about 20 chains south of Wilson's House, in biotite gneiss near a garnet gneiss band, suggest that this part of the area is on the eastern limb of an anticline slightly overturned to the east and pitching at about 40° to the south.

About 20 chains south of Marda Brook between No. 1 and No. 2 Creek is an area of a similar type of gneiss which is very contorted. The outcrops here swing round in a fairly narrow arc with convexity facing south from a strike of 45° at a point on the eastern side to 330° at 16 chains due west of this point. Readings of a dragfold at this point confirm the impression that this part of the area is the nose of an anticline pitching fairly steeply to the south. About 25 chains to the south-west is a band of ferruginous mica schist which swings from a north-westerly to a northerly strike and appears to be part of the same structure.

If this part of the area has a pitching anticlinal structure as suggested then the broad bend of felspathic quartzite near the junction of Marda Brook and Chittering Brook may be interpreted as a large dragfold. A highly idealised plan, showing this suggested structure, has been prepared (page 39).

B.—*The Metamorphic Rocks.*

The metamorphic rocks exposed in this area are probably an extension of what has been called the "Jimperding Series" (Clarke, 1930, p. 12). They constitute a very varied and irregular series of interbedded gneisses, micaceous schists, sillimanite and kyanite schists, and felspathic quartzite, which attain a possible thickness of 4,500 to 5,000 feet in the area mapped, though they are known to extend for at least a mile west of the western border of this area. These rocks form part of a belt of very ancient metamorphics which are probably of Yilgarn age. The belt extends eastwards to link up with the Jimperding metamorphics which have a predominant east-west strike and are characterised by thick beds of quartzite with interbedded gneiss, basic schist and micaceous schist, with gentle folding to the south (Prider, 1932-4). Farther east of Jimperding these metamorphics frequently show clear evidence of much stronger dynamic metamorphism, being thrown into steep folds, and the beds show considerable variation in thickness.

The metamorphic belt extends northwards from the Chittering Valley to Moora and some 110 miles north of this in the Irwin River district near Yandanooka are further occurrences of similar metamorphic rocks.

The belt stretches south-east from Jimperding to Clackline and extends to York. Another occurrence has been noted (Maitland, 1899, p. 28) between Northam and Goomalling.

Owing to the intensely folded and metamorphosed nature of the rocks, it is very difficult to determine the succession or the order of the beds in such a comparatively small area.

A few miles to the south-west of the area mapped are deposits of the Bullsbrook (? Jurassic) leaf beds but no sign of such beds were found here.

The predominant rock is a medium grained biotite gneiss which in places shows signs of intense folding and which occurs irregularly throughout most of the area, while interbedded with this gneiss are high-grade metamorphics, such as the sillimanite and kyanite schists, and garnet gneisses.

The metamorphics may conveniently be divided into—

1. The schists—micaceous, and basic.
2. The gneisses.
3. The "quartzites" or acid mylonite-gneisses.

This arbitrary division of the metamorphics is petrologically a rather artificial one as some of the members of the first group are more closely related to certain types of gneisses than to any other member of the schists, while structurally the division between a gneiss and a schist is frequently more apparent than real. However the grouping has the charm of comparative simplicity and for that reason has been adopted here.

1. *The Schists.*—These may be grouped as—

Micaceous schists consisting of—

(a) Sillimanite, kyanite schists.
(b) Lenticular mica schists.
(c) Ferruginous mica schists.

Basic Schist—Hornblende schist.

Micaceous Schists of the Lower Chittering area include an assortment of types extending from rather massive gneissic on one hand to highly laminated schistose on the other. There are marked differences in the mineral assemblages of the different groups in some cases, while in others there appears to be a gradual transition of one type into the other, indicating differing degrees of regional metamorphism in the area. There appear, however, to be several clearly marked horizons of schists. All these rocks have suffered rather intense weathering and fresh hand specimens are difficult to obtain.

(a) *The sillimanite—kyanite schists.*

This type ranges from rock which carries sillimanite with only accessory kyanite to one in which kyanite is present to the exclusion of sillimanite. The commonest type shows about equal development of both these minerals. The specific gravity varies considerably in specimens showing different stages of weathering, but the freshest range from 2.75-2.82.

In freshest hand specimens the micaceous schists vary from rather massive gneissic to finely schistose types of greyish white colour generally slightly stained with limonite. They consist of an abundance of medium fine granular quartz and interstial flakes of biotite of average grain size between 1 and 2 mms.

The sillimanite occurs as small, flat, yellowish-white coloured, soft furry plates with a typical silken lustre. These plates range from less than 1 mm. to 7 mms. in diameter and are oriented in the plane of schistosity. Kyanite is usually present in thin, elongated parallel plates, pale yellowish to colourless, up to 3 mms. in length which are frequently very difficult to recognise in hand specimen.

In thin section the texture is granoblastic, gneissic, seriate. The interstitial quartz grains frequently form a clear interlocking mosaic characteristic of recrystallisation textures. Kyanite crystals usually show diablastic structures, partially or completely surrounding rounded grains of quartz which have been enclosed during the growth of the kyanite and which indicate an early stage of crystalloblastic development. (Figs. 1 and 3.) Both kyanite and sillimanite are very frequently partially surrounded by, or embedded in, flakes of pale green-brown biotite in a manner which generally indicates a progressive metamorphism.

The sillimanite occurs in characteristic felted, or sheaf-like aggregates of elongated needles showing typical cross fracture, and is invariably associated with biotite. In one specimen (15385),* a kyanite sillimanite schist, sillimanite occurs in two markedly different sizes—rather coarser straight needles .02 mms. wide and up to 1.5 mms. long and also in fine acicular brushes embedded in biotite. (Fig. 2.) This suggests two distinct generations of the mineral (Harker, p. 324).

Biotite is an abundant constituent of all these rocks and occurs in irregular green-brown flakes which frequently carry strongly pleochroic haloes surrounding inclusions of zircon. These zircons which range from .03 mms. to .35 mms. in length are dark in colour and have rounded outlines.

Chlorite occurs occasionally in pale green, often radiating, laths pseudomorphous after biotite, indicating retrograde metamorphism. Staurolite was noted in a few specimens. It occurred in numerous small, yellow, pleochroic lath-like crystals up to .24 mms. long generally seen associated with crystals of biotite and chlorite.

In some types colourless micas, muscovite altered from biotite, and irregular fibrous flakes cf sericite suggesting stress conditions, are fairly abundant. A little finely twinned sodic plagioclase felspar associated with quartz is present in a few specimens.

(b) *Lenticular mica schist.*—This type occurs in one fairly persistent band some 8 or 9 chains wide and about a mile long in the north central portion of the area and in several small apparently isolated bands in other parts. The schists consist essentially of masses of flakes of colourless muscovite and pale greenish biotite, oriented to produce a strongly schistose or foliated structure in the rock. Intercalated in bands which pinch and swell irregularly is abundant granular quartz. The foliation planes of the mica curve around these irregular hard bands producing a peculiar "knotted" or lenticular structure in the schist. These lenticles vary from 3 cms. diameter to finer ripples less than 1 mm. in diameter.

* The figures in parentheses refer to catalogued specimens in the General Collection at the Geology Department, University of W.A.

A heavy mineral separation undertaken on one of these rocks produced abundant small dark, rounded prismatic crystals of zircon, one or two grains of kyanite, and a little staurolite.

(c) *Ferruginous mica schist.*—This rock occurs in the southern portion of the area. In hand specimen it is medium-fine grained and red coloured, due to the coating of all its constituents by iron oxide from weathering. It consists essentially of granular quartz and intercalated flakes of colourless mica oriented to produce a marked fissility. Numerous small flat plates of a soft whitish mineral are seen scattered throughout the rock in parallel orientation. Although this has the habit of sillimanite, powdered fragments examined microscopically showed no sign of the characteristic form and cleavage of that mineral, but on the other hand showed the form, cleavage, and low refractive index of sericite.

In thin section the rock is granoblastic schistose consisting of intercalated bands of interlocking, iron-stained quartz; associated biotite in shredded red-brown flakes; subhedral colourless muscovite; and colourless, fibrous sericite. The sericite occurs in frequent roughly continuous parallel oriented bands interstitial between quartz and biotite, and is possibly a pseudomorph after sillimanite.

Basic Schists:

Two distinct types of hornblende schist have been recognised in the area. The predominant, clearly of igneous origin, and found in the field intrusive into the gneisses, will be described later.

A few occurrences of a second type, a rather sandy hornblende schist, in places minutely foliated, and apparently embedded in the biotite gneiss, have been noted. This is a dark coloured, fine, even granular rock in which fine intercalated layers of quartz and short needle-like hornblende crystals form finely folded laminae. The crests of these minute folds are filled with coarser crystals of hornblende, individuals of which attain a length of 1.5 mms. The specific gravity is 3.00.

In thin section the hornblende consists of elongated prisms with blue-green pleochroism and is a fairly high grade amphibole with refractive index ranging from 1.665-1.675. The bluish colour is caused by the presence of soda and the mineral probably has a composition tending towards glaucophane.

Magnetite in numerous broken and parallel oriented grains is associated with the hornblende. These minerals are set in a mosaic of clear, recrystallised quartz, with a little twinned oligoclase felspar. Accessories are minute zircons, producing pleochroic haloes in the hornblende, a little apatite, and granular epidote.

2. *The Gneisses*:

The main bulk of the central part of the area consists of massive to finely banded acid rocks which range in mineralogical composition from highly acid types (approaching quartzites) to intermediate hornblendic varieties in which are found in one or two places, basic bands of a gneissic biotite hornblendite granulite.

The gneisses are divisible into the following types:—

(a) Biotite Gneiss.
(b) Hornblende Gneiss.
(c) Garnet Gneiss.
(d) Augen Gneiss.
(e) Hornblendite Granulite.

The first three types frequently appear, in the field, to grade into one another and are apparently interbedded with the schists. The augen gneiss forms a clearly defined band between 25 and 30 chains wide, extending the length of the area on the western side, bounded on one side by a micaceous sillimanite schist and in part on the other by a quartzitic slate.

(a) *Biotite Gneiss.*—This group included a series of acid rocks which show marked structural and textural differences but less varied mineral compositions. In the field some parts are found to be finely crushed, laminated, and drag-folded; others, less disturbed, and massive. The most abundant type is a medium fine grained, light grey coloured, rather massive, granitic gneiss with an average specific gravity of about 2.74. Frequently in hand specimen the gneissic banding is not very apparent. Other varieties often show a rather irregular porphyroblastic structure.

The texture of all these types is holocrystalline gneissic. In thin section they are granoblastic to porphyroblastic, and in some cases, porphyroclastic, gneissic. Recrystallisation, possibly with the addition of silica, potash and soda by granitisation processes, appears to be the predominant characteristic of some types, while in others granulation due to shearing stresses is a marked feature. The principal mineral components are quartz, in clear grains of varying size; sodic plagioclase, albite to oligoclase, generally in larger allotriomorphs, showing characteristic twinning and frequently carrying inclusions of apatite rods and the alteration product, sericite.

Microline occurs in subordinate amount in some specimens and when present bordering plagioclase generally shows the development of myrmekite. A little orthoclase is also occasionally seen. Biotite is abundant in oriented idiomorphic laths and flakes of green to brown colour, often arranged about the rims of crystalloblastic felspars (Fig. 6). It is typically fresh and unaltered and rarely contains inclusions of zircons with pleochroic haloes. Subhedral muscovite flakes are occasionally abundant. The accessories are apatite rods in felspar and biotite, broken crystals of iron ore, granular epidote, zircon occasionally in biotite, and a little sphene.

(b) *Hornblende gneiss.*—This type occurs apparently interbedded with biotite gneiss and appears to grade into bands of garnet gneiss in several places. In hand specimen this rock is medium grained, black and white coloured, consisting of intercalated layers of quartz and felspar, and oriented fine hornblende plates, and flakes of biotite producing a marked gneissic structure. Grain size is variable.

In thin section it is granoblastic gneissic to cataclastic, and consists essentially of bands of irregularly oriented crystals of hornblende up to 1.6 mms. long intergrown with brown biotite laths, set in a ground mass of broken irregular grains of quartz, potash and soda felspar.

The felspars are microcline, and twinned and untwinned albite-oligoclase, and associated with this is a little vermicular myrmekite formed at the borders between soda and potash felspars.

Accessories are epidote, iron ore, in the form of ilmenite often rimmed with sphene, rounded prismoids of zircon, and a little apatite.

(c) *Garnet Gneiss.*—The garnet gneisses of this area are divisible into two distinct types (I.) Garnet Hornblende Gneiss, (II.) Garnet Staurolite Chlorite Gneiss.

(I.) *Garnet Hornblende Gneiss* is present as a narrow band in hornblende gneiss, which grades into biotite gneiss in the north centre of the area. It is a black and white strongly banded rock consisting of alternate layers of quartz and amphibole. Scattered through the femic bands are abundant fractured crystals of red garnet ranging from 2 mms. up to about 8 mms. in diameter.

In section this type is similar in all respects to the normal hornblende gneiss described above, except for the addition of the pink garnet, which is probably almandine in rather shattered crystals generally associated with hornblende in a diablastic texture.

(II.) *Garnet-Staurolite-Chlorite Gneiss* in hand specimen, consisting of an aggregate of oriented quartz and black mica through which are scattered numerous crystals of broken, red garnet of variable size. In thin section the rock is granoblastic gneissic. The mineral constituents are:—quartz, which forms a background of an irregular interlocking mosaic; biotite in green brown plates altering to chlorite, occasionally with inclusions of iron ore, and zircons producing pleochroic haloes; chlorite, in abundant pale green sheaves, occasionally associated with biotite and frequently completely enclosing grains of pink almandine (Fig. 4). Staurolite is present in irregular groups of numerous short stumpy crystals frequently associated with biotite and chlorite. Accessories are iron ore (magnetite), granular epidote and rounded zircons.

The staurolite in this type appears to be quite fresh and in an early stage of development, while both the garnet and the biotite are altering back to chlorite.

(d) *Augen Gneiss.*—This type is coarsely crystalline, light grey coloured, consisting essentially of irregular bands or lenses of felspar up to 15 mms. wide and generally twice as long. These lenses are all roughly oriented to form a coarse "augen" structure, the interstitial material being a finer granular aggregate of quartz, felspar and biotite. The specific gravity averages about 2.72.

In thin section it is porphyroclastic gneissic with a cataclastic granular matrix.

The porphyroclasts consist of:—orthoclase in large plates up to 7 mms. long and 4 mms. wide; albite, and microcline, in smaller rectangular plates roughly 1.2 mms. in diameter. The plagioclase is usually rather turbid with alteration to kaolin and sericite, while microcline is characteristically fresh and shows irregular cross-hatching. The matrix consists of an aggregate of broken crystals of quartz, albite, microcline, and a little orthoclase, shredded flakes of brown biotite, undulating muscovite and fibrous sericite associated with granular epidote. Running through the matrix are a number of parallel, strongly mylonitised bands in which the felspars are almost entirely altered to flowing aggregates of sericite, with quartz and sphene, and one section was found to contain a single crystal of calcite.

(e) *Hornblendite Granulite.*—In this group have been placed two types of basic gneissic rock found in several irregular bands or segregations in biotite or hornblende gneiss.

One type is heavy, melanocratic, medium grained, and consists almost entirely of rather coarse crystals of hornblende, with accessory quartz, iron ore, epidote, and rounded zircons forming pleochroic haloes in the hornblende.

The second type is more acid and consists of intergrowths of hornblende crystals up to 1 mm. x .5 mm., with fresh laths of biotite up to .8 mm. long. Interstitial material is albite, oligoclase felspar, granular quartz, and sphene forming rims about ilmenite.

Accessories are:—apatite, zircon producing pleochroic haloes in both hornblende and biotite, rutile. The mineralogical composition and texture of this type suggests that it is a basic segregation of igneous origin.

3. *The "Quartzites."*

The definition of quartzite (Hatch & Rastall) as "a recrystallised sandstone in which all the original structures are destroyed and the whole is converted to a mosaic of clear formless quartz crystals without any regular outline but with closely interlocking, crenulated edges," can very seldom be said strictly to apply to the very acid quartzose types of rock described below.

Cataclastic rather than granoblastic structures are predominant and the term "mylonite gneiss" of Quensel (1916) which is "a rock partly granulated and partly crystallised, intermediate in its characters between mylonite and schist. The felsic minerals show cataclastic phenomena without much re-crystallisation, and often surrounded by, and alternating with, — — — recrystallised dark or mafic minerals," would appear to be more applicable in many cases, and quartz-felspar-mylonite-gneiss would probably be a more accurate, though rather cumbersome, name for felspathic "quartzite." However, the term "quartzite" will be used here in the description of these acid metamorphics which may show both cataclastic and recrystallisation structures. They may be divided into:—

(a) Felspathic "quartzite."
(b) Epidote "quartzite."
(c) Quartzitic slate.
(d) Fine grained quartzite.

(a) *Felspathic "quartzite."*—This type occurs persistently in a band about 15 chains wide and running for about three miles in a north-easterly direction on the eastern side of the area. It varies from a fine-grained cherty rock pale green in colour, carrying fine even bands of epidote, to a rather coarser grained yellow rock consisting of a granular aggregate of quartz, felspar and epidote. All types are flecked with small crystals of pyrite.

In thin section the finer grained types consist almost entirely of recrystallised equidimensional quartz averaging .08 mms. in diameter with fine oriented continuous stringers of epidote.

The coarser varieties show considerably less recrystallisation of the quartz, and contain abundant porphyroclasts of albite felspar which may show minute faulting (Fig. 5) and occasionally a little microline. Epidote may sometimes form irregular subhedrals crystals up to .3 mms. long.

(b) *Epidote "quartzite."*—This rock type occurs in a single thin band less than two chains wide and traceable for a distance of eight to ten chains along a north-south line in the centre of the area. The band shows a rapid increase of basicity across the strike from west to east, hand specimens being considerably darker in colour. The rock is medium grained, even granular, in hand specimen the minerals recognised being quartz, pale yellowish epidote, and parallel needle-like hornblende.

In section the rock consists essentially of a granoblastic aggregate of idioblastic granular to subhedral epidote with a birefringence ranging from that of pistacite to clinozoisite and zoisite, crystals being up to 3.5 mms. long, set in a matrix of interlocking quartz grains, averaging .9 mms. diameter, with subordinate blue-green hornblende, chlorite associated with epidote, and sphene in small granules. Accessory minerals are rounded prisms of apatite and zircon and a little iron ore.

(c) *Quartzitic slate.*—This type, which occurs in a region of strongly folded rocks in the western side of the area, is itself minutely contorted and dragfolded, and in hand specimen appears as a very fine grained, dark green coloured, finely laminated sediment, regularly foliated and contorted. It has a fine slaty cleavage along intercalated layers of dark flakey material and fine white coloured quartzitic bands. Irregular cubes of pyrite are scattered throughout.

In thin section the rocks consist essentially of layers of microcrystalline to cryptocrystalline quartz and felspar, and shredded chlorite, intercalated between fine bands of very fine grained quartzite.

(d) *Fine grained quartzite.*—This rock occurs in thin bands or lenses in mica-sillimanite schists, augen gneiss, and the quartzitic slate. It is very fine grained, massive, pink and white coloured, and consists entirely of fine interlocking, equidimensional, angular crystals of quartz averaging 0.1 mms. in diameter.

C.—*The Igneous Intrusives.*

The igneous rocks of this area are all intrusive into the metamorphics of the Chittering Series and they may be subdivided as follows:—

Acid intrusives—
- (a) Gneissic granite.
- (b) Aplite and associated pegmatites.
- (c) Quartz veins.

Basic intrusives—
- (a) Massive type—Dolerite and associated epidiorites.
- (b) Schistose type—Hornblende schists.

Acid Intrusives.

(a) *Granite (gneissic or stressed).*—The granite type of acid rock which in the field appears intrusive into the metamorphics is a medium grained type which shows a very constant mineralogical composition throughout its breadth in the area, in marked contrast to the acid gneissic metamorphics. In the structure this rock varies from a massive medium grained crystalline type in which rather irregular shredded flakes of biotite are distributed in irregular parallel bands, to a finer grained slightly darker coloured massive allotriomorphic granular rock in which any gneissic banding seen in hand specimen appears to be due to granulation by stress.

In the more granulated specimens secondary epidote is fairly abundant. The minerals of this rock as determined in thin sections are:—

Quartz—abundant in all specimens, occurring usually as irregular anhedral grains of varying size from large crystals up to 1.5 mms. diameter often showing undulose extinction, to small broken grains which are usually present as interstitial growths between felspars. The felspars are:—

Microcline is very abundant occurring in fairly fresh clear plates up to 1.55 mms. in diameter. Plates occasionally have embayed edges filled with quartz but very seldom carry myrmekite. It is usually fresh but some alteration to fibrous sericite may be seen. Frequently the "cross hatched" twinning is very irregular. Orthoclase in large subeuhedral rectangular plates up to 2 mms. diameter is frequently present. These plates often show considerable alteration to aggregates of granular sericite, epidote and kaolin, the inclusions of sericite occasionally being grouped thickly in a zonal band parallel and close to the rim of the felspar crystal.

Plagioclase occurs in numerous euhedral to subhedral crystals of variable size which may show zoning. The plagioclase is invariably rather heavily saussuritised and consists of a mat of sericite, zoisite, and epidote flakes. Original twinning in fine lamellae is frequently visible and extinction angles indicate albite—oligoclase.

The ferromagnesians are essentially biotite, muscovite and epidote. Biotite occurs typically in irregular greenish-brown, often rather altered pleochroic flakes and laths generally associated with granular epidote, and may carry inclusions of magnetite granules. In most specimens plates of brown biotite were found in which were dark needle inclusions of rutile arranged in an interlaced web structure known as sagenite webbing. Inclusions of zircon with strong pleochroic haloes, are also to be seen.

Muscovite is present usually in medium sized fresh sub- to euhedral plates and flakes in which can be distinguished two types, primary crystals idiomorphic towards epidote and biotite, and secondary, generally smaller laths, frequently showing alteration from biotite.

Epidote is a frequent mineral and is mainly secondary, occurring as granular aggregates associated with and generally forming from biotite. It is a pale yellowish mineral and is common epidote. One crystal associated with biotite with sagenite webbing shows similar webbing in its core. Epidote also occurs in veinlets cutting the felspars and quartz. Zoisite is abundant in fine granular aggregates in saussurite. Accessories are apatite, in abundant small rods and prisms; zircons, and rutile, are frequently included in biotite; iron ore occurs in occasional grains scattered through altered biotite or surrounded by a rim of epidote.

One or two specimens show development of a little myrmekite in microcline. In thin section, the similarity of this rock type to the gneissic granite of the Darlington Area is most marked.

Sagenite Webbing.—An interesting point in connection with this gneissic or granulated granite type, is the frequent occurrence in biotite of interlacing acicular needles of rutile which form sagenite webbing.

This webbing, which is probably due to heating of original biotite with the separation from it of its titanium content, in the form of rutile, has not been found in the biotite of any of the biotite gneisses of other metamorphics from the area under discussion, but appears to be a constant feature of the granite.

The occurrence of sagenite webbing has been remarked in the gneisses of the Jimperding area (Prider, 1932), which, it was suggested, may have originally been sediments. It has since been found in all the acid gneisses of the metamorphics in the areas, south and east of Toodyay, which have been mapped by University students during the last four years.

Sagenite webbing in biotite has also been noted in "grey granite" from the Upper Swan area (Fletcher & Hobson, 1931-2), but there appears to be no mention of its occurrence in the granite of the Darlington and Roleystone Areas.

(b) *Aplite and Associated Pegmatites.*—These are later than the granite and the metamorphics which they intrude. Occurrences of aplite in the field are rather rare, one specimen (1556) which was found in close proximity to a graphic pegmatite shows a fine-grained granular structure in hand specimen, and in section is seen to consist of medium fine-grained allotriomorphic granular clear quartz, and slightly altered albite-oligoclase felspar together with one or two flakes of altered biotite and granular epidote.

The pegmatites proper are of several varieties which consist essentially of coarse textured crystalline quartz and alkaline felspar, usually microcline, with a variable development of muscovite or biotite in coarse books which may measure from ½ inch to 2 inches in diameter and up to ½ inch thick. One biotite pegmatite (1551) carries numerous small dark segregations of magnetite up to ¾ inch in diameter. Several graphic pegmatites are present in the south. These consist of linear intergrowths of clear quartz and yellowish white microcline.

(c) *Quartz Veins.*—Vein quartz is very irregular in distribution and rather rare in occurrence in the area. As yet the relation of the quartz veins to the pegmatites is uncertain but the veins in the Chittering Series frequently show signs of some deformation and it is probable that they closely followed the aplite-pegmatite dyke phase.

An interesting occurrence of vein quartz has been noted in the western portion of the area in quartzitic slate on the site of an old prospecting "show" or costeen. The quartz is clear, colourless, massive crystalline and heavily sprinkled with pyrite in cubic crystals of varying size ranging from a fine "paint" coating cracks in the quartz to perfect single cubes and pyritohedrans 6-7 mms. in diameter.

Broken faces of these cubes which have been exposed to weathering for some time show brassy to bluish tarnishing indicative of the presence of copper. Blowpipe tests and also a number of wet-way tests carried out on fragments of this mineral failed, however, to provide any positive reactions for copper.

The Basic Intrusives.

The basic dyke rocks are all holocrystalline fine to medium grained with seriate texture, and with a colour varying from black to greyish green in the highly uralitised varieties. The dyke rocks may be divided into:—

(a) Massive types—Dolerites and Epidiorites.

(b) Schistose types—Hornblende Schist derived from (a) by dynamic stress.

(a) *The Massive types.*—Dolerites and quartz-dolerites. These are black, holocrystalline, generally medium grained, and in hand specimen can be recognised black pyroxene and light coloured, translucent, plate-like felspar. In thin section ophitic texture is well marked.

The minerals recognised are:—

Pyroxene: in subhedral to euhedral crystals, pale brownish to colourless, only faintly pleochroic. Cleavage is well marked and relief is high, extinction is variable. In sections with oblique extinction biaxial figures, which show that the section is nearly perpendicular to the acute bisectrix, are obtained, while sections with straight extinction give a figure characteristic of the emergence of an optic axis. The optical character is always positive. The relation of biaxial figure to extinction suggests a monoclinic pyroxene with small axial angle is probably enstatite-augite (Thomson, 1911, p. 305). Simple twinning is frequent. Even in freshest specimens the pyroxene shows alteration around the rims to pale green fibrous uralite.

Felspar: occurs in laths and plates of a marked dusty brown colour, which are ophitically intergrown with the pyroxene. These show the fine lamellar twinning of plagioclase, and sections cut perpendicular to the twin planes show extinction angles averaging about 24° and hence the felspar is labradorite.

Quartz: is present in the quartz-dolerites as small interstitial crystals associated with felspar.

Iron Ore: occurs frequently in abundant euhedral to skeletal crystals or subhedral grains of magetite with synantetic reaction rims (Sederholm, J. J., 1916) of green chlorite and ilmenite in skeleton crystals which may show incipient alteration to leucoxene.

Primary hornblende: occurs in subordinate amounts as dark green pleochroic subhedral crystals.

Brown biotite: occurs in a few irregular plates in some sections.

Accessories: apatite in short stumpy crystals or elongated needles most frequently occurs as inclusions in quartz in the quartz-dolerites; zircons are rare.

Epidiorites.—The mineral assemblage in this group is essentially the same as the dolerites, the chief difference being the much greater development of the secondary minerals, particularly uralite, and leucoxene from alteration of the primary pyroxene and ilmenite respectively, and frequently accompanied by almost complete destruction of the original ophitic texture.

Other secondary minerals are pale green chlorite growths forming by further alteration of uralite frequently intruding into the adjoining altered felspars. In many types which are in advanced stages of uralitisation the felspars may be completely altered to saussurite in mat-like intergrowths of granular zoisite, epidote, sericite, and fibrous chlorite which entirely mask the original form of the felspars.

Secondary sphene, forming borders around cores of ilmenite may also be seen occasionally. Secondary epidote may be produced in abundance replacing the saussurite in the alteration of plagioclase, one specimen (15358) being seen in section to consist almost entirely of epidote, fibrous uralite and chlorite, and leucoxene with subordinate granular quartz, and abundant accessory apatite.

There is no definite boundary line, either petrographical or in the field, between the dolerites and epidiorites. They form a continuous series of which dolerite and completely uralitised dolerite or epidiorite, are the two end points and all intermediate stages in the uralitisation are represented.

(b) *Schistose Type*—Hornblende schist.—This type is generally a medium-fine grained, dark green rock with a finely schistose structure, consisting of fine, needle-like parallel-oriented crystals of dark amphibole, irregularly scattered through which are irregular, small, even granular, white coloured flakes of felspar. In the field this schistose rock has been found to form the borders of some dykes, the centres of which are massive epidiorites.

A petrographical study of these schists leaves no doubt that they have been formed directly as the result of shearing of original typical epidiorites or dolerites.

In thin sections cut perpendicular to the plane of schistosity, may be seen specimens ranging from partially sheared and granulated epidiorites which show medium grained "augen" of unbroken epidotised plagioclase surrounded by parallel-oriented "flowing" fibrous uralite (1528), to a fine grained finely schistose type in which the presence of abundant granular zoisite intercalated with uralitic hornblende, is the only trace of the original plagioclase (15316).

The less altered varieties may contain fairly fresh, slightly dusty felspars, with broken edges, and associated with these is amphibole in subhedral to euhedral, fresh blue-green, pleochroic laths, with a refractive index ranging from 1.668 to 1.674, and which is probably a glaucophanic variety. This is probably produced by recrystallisation from original uralite, with absorption of some soda from the felspar. The epidote and zoisite occurs in granular aggregates, with epidote also occasionally in larger crystalloblasts of pale yellow-brown colour.

The plagioclase when fresh, usually shows the cloudiness characteristic of the felspar in the dolerites, and the extinction angles of lamellar twins indicates a composition near that of labradorite. The felspars more often show, however, almost complete alteration to granular epidote, zoisite and fibrous chlorite. Chlorite is present in pale green fibrous shreds, in examples of the early stages of alteration but is not found in the more completely sheared types.

Iron ore is an abundant accessory occurring as small euhedral crystals of magnetite and more frequently irregular, broken, and lensed out granules of ilmenite surrounded by rims of granular sphene.

Quartz may occur abundantly in granulated aggregates intercalated between bands of epidote, and may be partly primary, derived from original quartz-dolerites, and partly secondary from the epidotisation of the plagioclase.

Apatite is frequently present in needles and short crystals embedded in quartz and altered felspar. Zircons giving pleochroic haloes in the hornblende are rarely present.

Clouded Felspar.—An interesting feature of the felspars of the basic igneous rocks in the area is that especially in the dolerites, whilst remaining perfectly fresh, they show a peculiar dusty-brown clouding by a substance so finely divided as to be unrecognisable even under very high power microscopes. These felspars are intermediate plagioclase with a composition approaching that of labradorite. In the epidiorites this brown clouding is frequently a marked feature of the fresher felspar, though it may be quite masked in many cases by the development of saussurite.

In the less strongly sheared epidiorites, some broken crystals of felspar may show clouding, but in those hornblende schists, in which dynamic metamorphism has been rather more intense and has been accompanied by recrystallisation of the felspar, the new crystals are perfectly clear and unclouded.

These phenomena agree closely with the occurrences of clouded felspar in metamorphosed dykes of Scourie District, Sutherland, Scotland, as described by A. G. MacGregor (1931).

MacGregor suggests that the dusty inclusions are due to a heating up and baking of the basic intrusives at some period after their consolidation. This baking causes minute traces of iron oxide (always present in the more basic plagioclases) and water, to separate out and cloud the felspars. Subsequent more intensive dynamothermal metamorphism has caused the breaking down of the original felspars, which have recrystallised unclouded. This opinion has more recently been confirmed by G. A. Joplin (1933), working in New South Wales.

D.—Later Rocks.

1. *Duricrust.*—A brief statement of the distribution of the duricrust plateaux in the area has already been given. The deposit is of two distinct types—the pisolitic variety of laterite which has been fully described from

other Darling Range areas, and a ferruginous grit which is found at a lower level and which possibly underlies the ubiquitous laterite type. This ferruginous grit is probably comparable with the ferruginous sandstone of the Upper Swan area (see above). The grit consists of numerous irregular, rounded and angular, grains of white quartz up to 10 mms. in diameter and occasionally small flakes of muscovite set in a dark red ferruginous matrix of fine grain. It is found overlying various types of both igneous and metamorphic rocks and appears to develop particularly well over ferruginous mica schist.

It appears as one progresses up the hill-slopes, to grade into laterite at between 750 feet and 800 feet. Most probably the iron in both the grit and the upper laterite was ultimately derived from the same source.

2. *Talus Slopes.*—Many of the steeper slopes in the area are covered with thick mantles, occasionally showing a terraced formation, of rubble or talus produced by the disintegration of dolerite, granite or gneiss. In some cases these talus slopes have been partly covered by loose soil. Heavy rains frequently cause land slips of this unconsolidated material, which is therefore unsuitable for cultivation and in places where the vegetation has been removed, presents a serious problem for the farmer.

3. *Alluvium.*—Mention has already been made of the presence of alluvium along the flood plain of the Chittering Brook. The stream is still actively degrading its bed, however, and only small deposits of alluvium are to be found. During flood periods, rise in the level of the Avon River tends to dam back the waters of the Chittering, which may deposit some of its coarser material, but the pressure is quickly released by the Avon, and the resultant rapid scouring action of the Chittering removes most of this silt. Such action during phenomenal floods may have been responsible for the terraces in some parts of the Lower Chittering Valley.

IV.—THE METAMORPHISM AND ORIGIN OF THE CHITTERING SERIES.

As previously stated, the Chittering Series is an assemblage of metamorphic rocks which conveniently fall into three main groups:—

Schists,
Gneisses,
Quartzites.

Any discussion of the origin of these rocks must primarily be dependent for its conclusion upon the recognition of the type of metamorphism which has been at work, and upon a proper interpretation of the products of such metamorphism as exposed in the area to-day.

A.—The Metamorphism.

The regional metamorphism in this area appears to have been rather complex, varying in grade and intensity over quite small areas. There can be seen all gradations from that characteristic of the "epizone" conditions of Grubenmann (1910) where temperature is moderate, hydrostatic pressure low, and shearing stress is the chief agent of metamorphism, to that of the deep seated types of the "katazone," where temperatures and pressures have been high, and stress has played a relatively unimportant part.

Among the crystalline schists, the minerals chlorite, biotite, hornblende, garnet, staurolite, kyanite and sillimanite, are present. These have been used by Barrow (1912) and Tilley (1925 and 1930) to distinguish well marked zones of thermal metamorphism of original argillaceous sediments in the Highlands of Scotland.

The distribution of these index minerals in the Chittering Series appears to be rather sporadic and no definite zones of metamorphism have yet been recognised. Probably, with extended mapping of the district, gradations in metamorphism, characterised by the predominance of one or more of the above minerals, may show an orderly sequence.

From a petrographical examination of the rocks, one can frequently recognise progressive changes in the degree of metamorphism. These changes are most clearly demonstrated in those members of the schist group which contain the minerals kyanite and sillimanite. Kyanite and sillimanite are the index minerals for the highest grades of regional metamorphism of the pelitic type of sediments. Kyanite is formed characteristically under conditions of great pressure though not excessive temperature, and is a typical stress mineral (Harker, p. 150). Sillimanite is stable under conditions of great pressure and temperature and is indicative of the highest grade of metamorphism.

The kyanite crystals, where developed in the schists, invariably show diablastic or poikilo-blastic intergrowths with quartz. This suggests that the kyanite had only reached an early stage of crystalloblastic development as prolonged or more intense metamorphism would have permitted of the growth of idioblastic crystals more or less free from inclusions. Thus, very probably no portion of the area mapped was ever subjected to prolonged metamorphism of the highest grade. On the contrary, some types of schist contain assemblages of minerals, of which some are not in equilibrium, and whose presence indicates a lag effect during retrograde metamorphism. This retrogressive metamorphism is probably induced by cooling under diminished pressure either as the last phase of the primary regional metamorphism, or after some later period of heating.

Progressive metamorphism is clearly shown in types such as 15338 which consists of a matrix of recrystallised quartz with intercalated chlorite, which can be seen altering to biotite. Associated with the biotite are small staurolite grains and a little sillimanite. In type 15376 there is also abundant kyanite in small crystals showing diablastic structures.

Staurolite, indicative of an intermediate thermal stage is frequently missing in these rocks. Some specimens (*e.g.*, 15372) which have a strongly marked schistose structure, contain only diablastic kyanite developing from biotite, with no sillimanite. This indicates recrystallisation under conditions of great stress and only moderately high temperature.

Retrogressive metamorphism without stress is shown by types 15330 and 15379, where sillimanite, kyanite and biotite can be seen altering to chlorite. An example of retrograde metamorphism under stress is given by type 15674 in which sillimanite and biotite are altering to white mica, while fairly large anhedral crystals of kyanite, though mechanically fractured, have remained stable.

A very interesting example of the effect of lagging during retrograde metamorphism is to be seen in one specimen of a garnetiferous gneiss (15364), in which pink garnet, probably almandine, and biotite, are altering to chlorite which contains many inclusions of small, strong, freshly formed staurolite prismoids. Apparently the cycle of progressive thermal metamorphism had reached the stage of the development of staurolite, when retrogressive metamorphism was initiated with a decrease in the temperature. The garnet and biotite have responded to the new conditions, but the staurolite has failed to react.

The mineralogical composition of the gneisses and quartzites is such that they are far less responsive, than the schists, to changed conditions of temperature and pressure. The predominant textures in the "augen" gneiss and the "quartzites" are cataclastic, indicating rather intense stress under "epi-zone" conditions.

The principal rock type of the series, the biotite gneiss, has textures varying from granitic to granoblastic, in which recrystallisation has taken place under moderate temperature-pressure conditions, as shown by the development of fresh-looking crystalloblastic felspar rimmed by idiomorphic biotite laths.

A higher grade of metamorphism of this rock is shown by the replacement of the biotite by dark green diablastic hornblende, indicating an increase in stress. The appearance of garnet enclosing quartz and hornblende in a garnet-hornblende-gneiss marks the highest grade of metamorphism of this type of rock.

Mechanical deformation of the garnet, however, indicates a later shearing stress. This stress may have been responsible for the mylonitisation of the felspathic "quartzite" and the augen gneiss.

B.—*Origin.*

No reliable chemical analyses of any of the rocks of this area have as yet been made, and so criteria to be discussed in connection with the origin of the Chittering Series must be confined to those based on the field occurrence and on mineralogical characteristics.

(1) *The Schists.*—In the field the schists show rather rapid changes in composition across the strike which is characteristic of original sedimentary, rather than igneous rocks. Also the schists vary frequently in structure and composition along the strike. These changes are so rapid and marked that it seems reasonable to explain them as due to the co-operation of two factors —variation in the character of the original rock and variation in the degree of metamorphism.

In hand specimen the lenticular mica schist shows the structure typical of a highly sheared impure sandy conglomerate, traces of original rounded quartzitic pebbles being clearly visible and the whole appearance strongly suggests a sedimentary origin for this rock type.

The mineralogical composition of the sillimanite, kyanite, and staurolite bearing schists, and the garnet-chlorite-staurolite gniess is consistent with that of a metamorphosed pelitic sediment, probably an argillaceous sandstone (Tilley, C. E., 1926). A notable feature of these rocks is the presence of abundant dark, rounded zircons. These zircons have all the characteristics of detrital grains which have remained stable and unaltered throughout the different grades of metamorphism to which the rocks have been subjected.

Opinion as to the validity of the use of zircons in metamorphic rocks as a criterion of their origin, is at present divided. Trueman (1912) postulated that the presence of abundant well-rounded zircons was a fairly safe indicator of an original sedimentary rock. He is followed by Winchell (1924) and Harding (1931), who both use the presence of well rounded heavy minerals, including zircons, to conclude a sedimentary origin for certain metamorphic rocks. C. G. Carlson (1920) and P. Armstrong (1922), however, point out that during the shearing and resultant granulation of an igneous rock, any original zircons in it may acquire rounded edges, and they also give examples of the occurrence of well-rounded zircons in undoubted igneous rocks.

However, the abundance and the darkened and pitted appearance of the zircons in the above-mentioned rock types is not inconsistent with, but to the author's mind rather supports, the assumption of their sedimentary origin.

The basic hornblende schist grouped with the schists, differs markedly in composition, as has been shown, from the sheared epidiorites, which are probably much younger. The hornblende needles show pleochroic haloes about zircon grains, which is a common occurrence in the Chittering Series. The mineral composition provides no decisive evidence of their origin.

2. *The Gneisses.*—Biotite gneiss is abundantly distributed throughout the central portions of the area, but is by no means uniform in composition or structure. Basic bands are found grading into more acidic, and massive types into bands showing ptygmatic veinlets of quartz and pegmatite. Many outcrops remind one of descriptions of Sederholm's "migmatites" (1923 and 1926).

Fine-grained biotite gneiss may have textures ranging from granitic to markedly crystalloblastic in which clear plates of plagioclase felspar show small laths of biotite moulded around their margins. Some types of biotite gneiss carry rounded grains of zircon, similar to those found in many of the schists, enclosed in biotite. Probably the best explanation of the origin of this rock type is that it is part sedimentary, part igneous; that it consists of refused pelitic material which has been intimately penerated under Katazone conditions by acid magmatic solutions, and that the resulting plastic mass, after a certain amount of fluidal movement producing ptygmatic veins, has recrystallised as biotite gneiss.

The origin of these postulated magmatic solutions is unknown but the gneissic granite which is believed to be much younger than the "granitisation" period probably was not derived from the same source. The hornblendite granulites were possibly basic seggregations in this recrystallised material.

The hornblende gneiss and hornblende-garnet gneiss may be considered as genetically related to the biotite gneiss, representing progressively higher grades of dynamic and thermo dynamic metamorphism.

The augen gneiss in the west of the area shows a remarkably constant mineralogical composition throughout, but apart from the evidence of intense dynamic stress, the mineral structure furnishes little to indicate its origin. In the field, the gneiss is interbedded between two undoubted para-metamorphics which may suggest a sedimentary origin for this type (Cp. Jimperding Area).

Possibly this is an injection gneiss which originally formed an igneous sill or sheet. The sillimanite-mica schist on the western border of this gneiss may then represent a contact metamorphic zone.

3. *The "Quartzites."*—The field occurrence of the felspathic "quartzite" rather suggests some relation between it and the gneissic granite which in many places appears to form its eastern boundary. This "quartzite" shows evidence of strong dynamic stress which may have been caused by the intrusion of the granite.

The mineralogical composition of this "felspathic quartzite" is not inconsistent with that of an original impure sandstone (Turner, E. J., 1935, p. 412), but it may equally well represent original acid igneous material.

The "epidote quartzite" in field occurrence, structure, and composition, strongly suggests its para-metamorphic origin. The high content of lime shown by the presence and habit of the abundant epidote which occurs in crystalloblastic aggregates associated with a little poikiloblastic hornblende set in a recrystallised quartzitic matrix, indicates an original impure, rather calcareous, sandstone.

The quartzitic slate is undoubtedly a pelitic sediment which has undergone remarkably little metamorphism. This is abundantly clear from an examination of the micro structure. This rock, however, may yet prove to be a down-faulted relict of a much later series, though up to the present no convincing field evidence for this has been remarked.

For the fine grained quartzite, both field occurrence and the composition is consistent with that of pristine pure, fine-sand bands in the pelitic material now forming mica schists, gneisses and quartzitic slate.

V.—GEOLOGICAL HISTORY OF THE AREA.

Until the structure of the area which has been mapped, to date, in the Lower Chittering Valley, has been worked out, the age relations of the different metamorphics of the Chittering Series must remain in doubt and consequently no definite statement regarding the geological history of the area should be made. However, it may be as well to give a brief summary of the writer's opinions as to the history, acquired from a study of metamorphism.

As has been shown, the Chittering Series consists of a series of metamorphosed sediments, and possibly some acid igneous gneisses, which have been intruded by later acid and basic intrusives.

The bulk of the metamorphics probably originally consisted of a series of sandy shales interbedded with thin bands of sandstone, grit and conglomerates, and possibly a little calcareous mudstone. These sediments were probably laid down in early pre-Cambrian time (perhaps early Yilgarn) and in all likelihood a little earlier than the Jimperding Series.

These sediments were deeply buried and subjected to great temperatures and pressures which caused the beds to become strongly folded and partly fused. The result of these conditions was to produce predominantly highly schistose micaceous rocks containing the aluminous silicates, sillimanite and kyanite. Probably during the final stages in the development of these schists, or possibly in some later period, great quantities of very fluid acid igneous material, by some process of magmatic stoping, entered the sediments and penetrated many parts of them intimately. This "peaceful penetration" would be most easily effected in the weaker and more schistose micaceous bands. The action of these very siliceous, potash and soda-bearing solutions would be to convert aluminous silicates to mica, and to cause the crystallisation of quartz and the acid felspars now seen in the biotite gneisses.

Later, the area was intruded by undoubted igneous rocks. The first was a granite bathylith which entered the area from the east. This granitic magma which probably had an entirely different source from the "granitising" solutions mentioned above, and may have been concomitant with, or a part of, the great Darling Range bathylith, was very likely not accompanied by great heat and was followed by a pegmatite phase.

The final phase of igneous activity is represented by basic dyke rocks which intruded all the pre-existing rocks along swarms of fissures which ran in roughly north-south directions parallel to the axes of folding of the metamorphics. Many of these dykes acquired a schistose structure, either due to earth movements practically contemporaneous with the intrusion, or as the result of a later regional stress which followed a period of increased thermal action. This regional stress may have been responsible for many of the cataclastic structures now seen in some of the acid types of rock.

The area was then subjected to long continued erosion. There is no direct evidence of any later accumulation of extensive sedimentary series since pre-Cambrian times. A few miles to the south-west of the Lower Chittering area, the Bullsbrook leaf-bearing shales, which are believed to be of Jurassic age, are found overlying gneiss. It is quite possible that this series originally extended over the area under discussion and that later denudation has removed all trace of them, except perhaps, the remarkably unaltered quartzitic slate described above.

The superficial capping of the ubiquitous laterite or duricrust is considered (Woolnough, W. G.. 1918, p. 385) to belong to a recent period when a great part of W.A. had been reduced to a peneplain.

Since that time, the area has undergone further denudation and dissection by streams as has been outlined in an earlier section of this paper.

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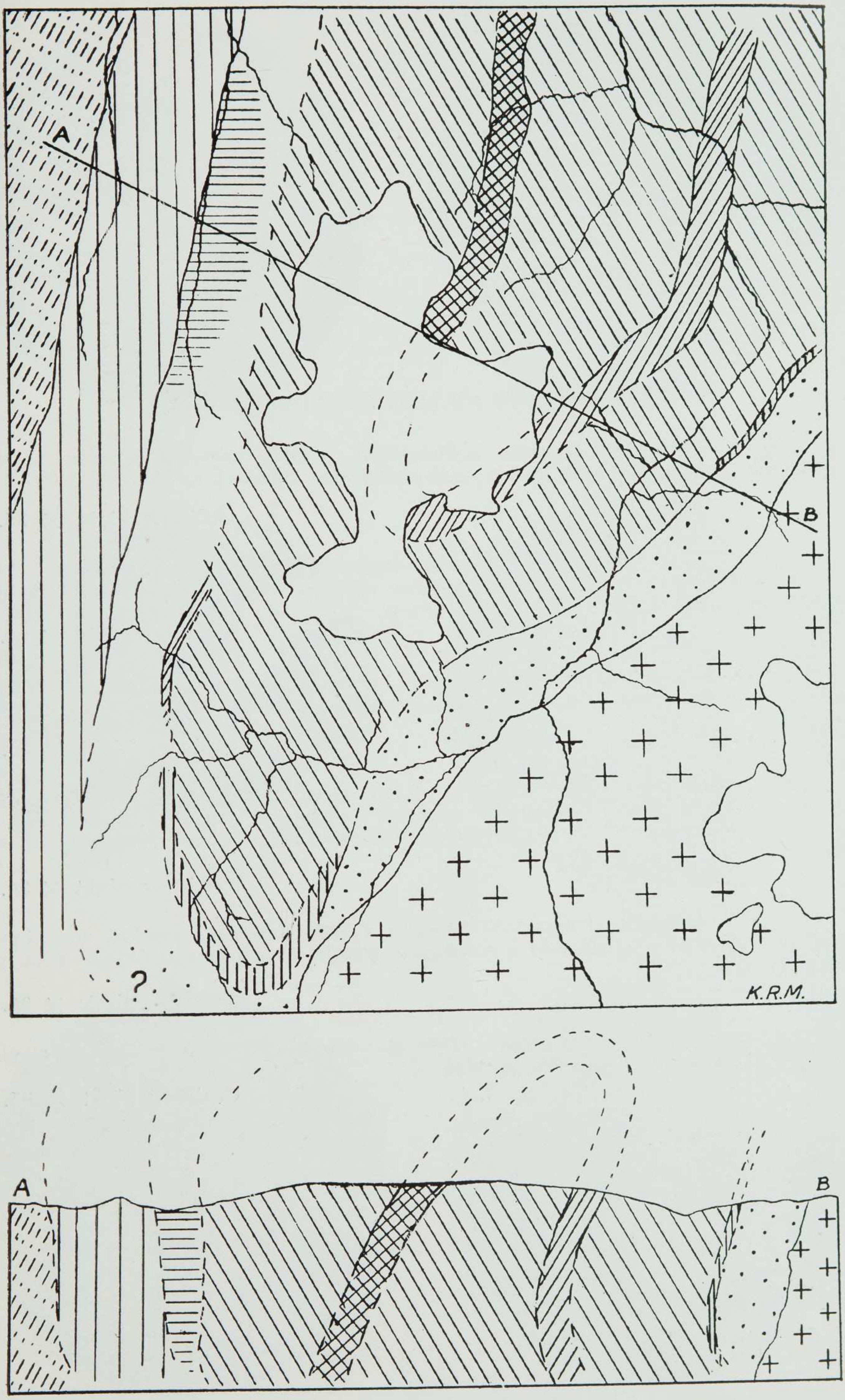

Idealised Plan and Section showing Suggested Structure of the Area. For Legend, see Geological Map.

EXPLANATION OF MICRO-PHOTOGRAPHS.

Fig. 1.—*Sillimanite-Kyanite Schist*—Spec. 15379, showing kyanite in a diablastic intergrowth with quartz, and sillimanite enclosed in chlorite.

Ordinary Light × 35.

Fig. 2.—*Kyanite-Sillimanite Gneiss*—Spec. 15385, showing sillimanite in coarse needles, and brushes of fine acicular needles; and associated biotite with pleochroic haloes about inclusions of zircon.

Ordinary Light × 34.

Fig. 3.—*Kyanite Schist*—Spec. 15372, showing kyanite developing from biotite with diablastic inclusions of quartz and a rounded zircon.

Ordinary Light × 35.

Fig. 4.—*Garnet-Chlorite-Staurolite Gneiss*—Spec. 15364, showing portions of garnet crystals, partly surrounded by, and altering to chlorite. A few small prisms of staurolite are scattered through the chlorite. The colourless mineral is quartz.

Ordinary Light × 34.

Fig. 5.—*Felspathic "Quartzite"*—Spec. 15349, showing a cracked and slip-faulted crystal of oligoclase in a cataclastic matrix of quartz and felspar with a little epidote.

Crossed. Nicols × 35.

Fig. 6.—*Biotite Gneiss*—Spec. 1518, showing biotite laths arranged round the periphery of a plagioclase crystal.

Ordinary Light × 35.

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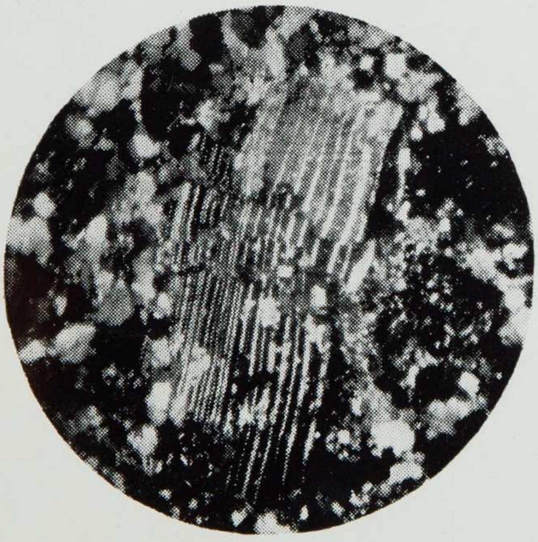

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MICROPHOTOGRAPHS.